(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 355 038 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
22.10.2003 Bulletin 2003/43

(51) Int Cl.7: E21B 43/267, E21B 47/10

(21) Application number: 03252392.0

(22) Date of filing: 15.04.2003

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IT LI LU MC NL PT RO SE SI SK TR
Designated Extension States:
AL LT LV MK

(30) Priority: 18.04.2002 US 125171

(71) Applicant: Halliburton Energy Services, Inc.
Duncan, OK 73536 (US)

(72) Inventors:
- Nguyen, Philip D.
  Duncan, Oklahoma 73533 (US)
- Weaver, Jimmie D.
  Duncan, Oklahoma 73533 (US)
- Barton, Johnny A.
  Marlow, Oklahoma 73055 (US)

(74) Representative: Wain, Christopher Paul et al
A.A. Thornton & Co.
235 High Holborn
London WC1V 7LE (GB)

(54) Tracking of particulate flowback in subterranean wells

(57) Compositions comprising a particulate material and a tracking material are used for tracking particulate flowback in wells. The tracking material is selected from metals, metal salts of organic acids, phosphorescent pigments, fluorescent pigments, photoluminescent pigments, oil soluble dyes, oil dispersible dyes and oil dispersible pigments.

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Description

[0001] This invention relates generally to tracking particulate flowback in subterranean wells and, more particularly, to a traceable non-radioactive particulate composition and its use downhole as a tracking material during the production of hydrocarbons from a subterranean formation penetrated by a well bore.

[0002] Transport of particulate solids during the production of hydrocarbons from a subterranean formation penetrated by a well bore is a continuing problem. The transported solids can erode or cause significant wear in the hydrocarbon production equipment used in the recovery process. The solids also can clog or plug the well bore thereby limiting or completely stopping fluid production. Further, the transported particulates must be separated from the recovered hydrocarbons adding further expense to the processing. The particulates which are available for transport may be present due to an unconsolidated nature of a subterranean formation and/or as a result of well treatments placing particulates in a well bore or formation, such as by gravel packing or propped fracturing.

[0003] In the treatment of subterranean formations, it is common to place particulate materials as a filter medium and/or a proppant in the near well bore area and in fractures extending outwardly from the well bore. In fracturing operations, proppant is carried into fractures created when hydraulic pressure is applied to these subterranean rock formations to a point where fractures are developed. Proppant suspended in a viscosified fracturing fluid is carried outwardly away from the well bore within the fractures as they are created and extended with continued pumping. Upon release of pumping pressure, the proppant materials remain in the fractures holding the separated rock faces in an open position forming a channel for flow of formation fluids back to the well bore.

[0004] Proppant flowback is the transport of proppants back into the well bore with the production of formation fluids following fracturing. This undesirable result causes undue wear on production equipment, the need for separation of solids from the produced hydrocarbons and occasionally also decreases the efficiency of the fracturing operation since the proppant does not remain within the fracture and may limit the width or conductivity of the created flow channel. Current techniques for controlling the flowback of proppants include coating the proppants with curable resin, or blending the proppants with fibrous materials, tackifying agents or deformable particulates (see, for example, U.S. Patents Nos. 6,328,105, 6,172,011 and. 6,047,772). For a multi-zone well that has been fractured with proppant and is plagued with proppant flowback problems, it is quite difficult to identify the zone from which the proppant is emanating unless the proppant is tagged with a tracer. Radioactive materials have been commonly used in the logging or tagging of sand or proppant placement, however, such radioactive materials are hazardous to the environment and the techniques for utilizing such radioactive materials are complex, expensive and time consuming. Therefore, there is a need for simple compositions and methods for tracking the flowback of proppant in subterranean wells to avoid the above problems.

[0005] In one aspect, the invention provides a traceable particulate composition for treating a subterranean formation having multiple zones penetrated by a well bore, said composition comprising a particulate material; and a tracking material, wherein the tracking material is selected from metals, metal salts of organic acids, phosphorescent pigments, fluorescent pigments, photoluminescent pigments, oil soluble dyes, oil dispersible dyes and oil dispersible pigments. In another aspect, the invention provides a method of treating a subterranean formation having multiple zones penetrated by a well bore which method comprises introducing a traceable particulate composition of the invention, into each zone using a different particulate composition in each zone to provide a different tracking material in each zone; flowing fluid back from the subterranean formation whereby at least a portion of at least one of the particulate compositions flows back from the subterranean formation; and identifying each zone in which the at least one particulate composition was introduced by detecting the tracking compositions in the fluid that flows back from the subterranean formation.

The invention further includes a method of propping multiple fractures in a subterranean formation penetrated by a well bore comprising: placing a proppant composition in each fracture in the subterranean formation, wherein each proppant composition comprises particulate material and a tracking composition, and wherein each proppant composition comprises a different tracking composition; flowing fluid back from the subterranean formation whereby at least a portion of at least one of the proppant compositions flows back from the subterranean formation; and identifying each fracture in which the at least one proppant composition was placed by detecting the tracking compositions in the fluid that flows back from the subterranean formation.

[0006] According to one embodiment of the invention, metals are tagged onto proppant material or materials to be blended with proppant material to provide for the ready identification of flowback proppant from different stages or zones of the well. Suitable metals for this purpose may be selected from Groups I to VIII of the Periodic Table of the elements as well as the lanthanum series rare earth metals so long as the metals do not constitute a component of the proppant, the fracturing fluid or the reservoir fluid and so long as the metals are compatible with the fracturing fluid. Preferred metals include gold, silver, copper, aluminum, barium, beryllium, cadmium, cobalt, chromium, iron, lithium, magnesium, manganese, molybdenum, nickel, phosphorus, lead, titanium, vanadium and zinc as well as derivatives thereof including oxides, phosphates, sulfates, carbonates and salts thereof so long as such derivatives are only slightly soluble in water so that they remain intact during transport with the proppant from the surface into the fractures. Par-

ticularly preferred metals include copper, nickel, zinc, cadmium, magnesium and barium. The metal acts as a tracer material and a different metal is tagged onto the proppant, or onto the materials to be blended with the proppant, so that each proppant stage or each fracturing job treatment can be identified by a unique tracer material. Suitable metals for use as the tracer material are generally commercially available from Sigma-Aldrich, Inc. as well as from Mallinckrodt Baker, Inc. It is understood, however, that field grade materials may also be used as suitable tracer materials for tagging onto proppant material or materials to be blended with proppant material.

[0007] Samples of flowback proppant collected from the field may be analyzed according to a process known as the inductively-coupled plasma (ICP) method to determine from which proppant stage and which production zone the proppant has been produced. According to the ICP method, an aqueous sample is nebulized within an ICP spectrophotometer and the resulting aerosol is transported to an argon plasma torch located within the ICP spectrophotometer. The ICP spectrophotomer measures the intensities of element-specific atomic emissions produced when the solution components enter the high-temperature plasma. An on-board computer within the ICP spectrophotomer accesses a standard calibration curve to translate the measured intensities into elemental concentrations. ICP spectrophotometers for use according to the ICP method are generally commercially available from the Thermo ARL business unit of Thermo Electron Corporation, Agilent Technologies and several other companies. Depending upon the model and the manufacturer, the degree of sensitivity of currently commercially available ICP spectrometers can generally detect levels as low as 1 to 5 parts per million for most of the metals listed above.

[0008] It is understood that depending on the materials used as tagging agents, other spectroscopic techniques well known to those skilled in the art, including atomic absorption spectroscopy, X-ray fluorescence spectroscopy, or neutron activation analysis, can be utilized to identify these materials.

[0009] According to another embodiment, an oil-soluble or oil-dispersible tracer comprising a metal salt, metal oxide, metal sulfate, metal phosphate or a metal salt of an organic acid can be used to tag the proppant by intimately mixing the metal with a curable resin prior to coating the curable resin onto the proppant. Preferably, the metal is selected from the Group VIB metals, the Group VIIB metals, and the lanthanum series rare earth metals. Specifically, the metal according to this embodiment may be chromium, molybdenum, tungsten, manganese, technetium, rhenium, lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium and lutetium. It is preferred that the metals according to this embodiment, do not constitute a component of the proppant, the fracturing fluid or the reservoir fluid, and that the metals are compatible with the fracturing fluid. Preferably, the organic acid is a substituted or unsubstituted carboxylic acid. More preferably, the organic acid may be selected from alkanoic and alkenoic carboxylic acids, polyunsaturated aliphatic monocarboxylic acids and aromatic carboxylic acids. Most preferably, the alkanoic carboxylic acids have from 5 to 35 carbon atoms, the alkenoic carboxylic acids have from 5 to 30 carbon atoms, the polyunsaturated aliphatic monocarboxylic acids may be selected from the group of sorbic, linoleic, linolenic, and eleostearic acids and the aromatic acids may be selected from the group of benzoic, salicylic, cinnamic and gallic acids. Suitable organic acids are generally commercially available from Sigma-Aldrich, Inc. as well as from Mallinckrodt Baker, Inc.

[0010] For proppant to be coated with a curable resin, the tracer agent is blended homogeneously with the resin mixture and the resin is then coated onto the proppant. The proppant can be precoated as in the case of curable resin-coated proppants, for example, such as those commercially available from Santrol or Acme Borden, or it can be coated on-the-fly during the fracturing job treatment. The nature of the resin materials and the processes for performing the coating process is well known to those skilled in the art, as represented by U.S. Patent No. 5,609,207 to which reference should be made for further details. Also, it is understood that materials to be blended with proppant such as the fibrous materials, tackifying agents or deformable beads disclosed in U.S. Patents Nos. 6,328,105, 6,172,011 and 6,047,772 to which reference should be made for further details.

[0011] According to still another embodiment, the metal elements or their derivative compounds can be tagged as part of the manufacturing process of proppant. As a result, the proppant is tagged with a permanent tracer.

[0012] According to yet another embodiment, the proppant can be coated with phosphorescent, fluorescent, or photoluminescent pigments, such as those disclosed in U.S. Patents Nos. 6,123,871, 5,498,280 and 6,074,739 to which reference should be made for further details. According to this embodiment, the phosphorescent, fluorescent, or photoluminescent pigments may be prepared from materials well known to those skilled in the art including but not limited to alkaline earth aluminates activated by rare earth ions, zinc sulfide phosphors, aluminate phosphors, zinc silicate phosphors, zinc sulfide cadmium phosphors, strontium sulfide phosphors, calcium tungstate phosphors and calcium sulfide phosphors. Suitable phosphorescent, fluorescent and photoluminescent materials are commercially available from Keystone Aniline Corporation (TB Series) and Capricorn Chemicals (H Series and S Series Glowbug Specialty Pigments). The particular structure of the materials has a strong capacity to absorb and store visible light such as sunlight or light from artificial lighting. After absorbing a variety of such common visible light the phosphorescent, fluorescent, or photoluminescent materials will glow in the dark. Various pigment colors can be combined with the luminescent capability of the materials to enhance the differentiation of the stages or zones. According to this embodiment, micron sized particles of the phosphorescent, fluorescent, or photoluminescent materials are intimately mixed

with a resin to be coated onto a proppant to be used in a fracturing treatment.

[0013] According to still another embodiment, proppant materials having a naturally dark color can be dyed or coated with a marker material having a bright, vivid and intense color which marker material may be selected from oil soluble dyes, oil dispersible dyes or oil dispersible pigments. Suitable oil soluble dyes, oil dispersible dyes and oil dispersible pigments are well known to those skilled in the art and are generally commercially available from Keystone Aniline Corporation and Abbey Color. According to this embodiment, proppant materials having a dark color, such as bauxite proppant which is naturally black in color, are dyed or coated with such marker materials. In this regard, reference is made to the dyes disclosed in U.S. Patent No. 6,210,471 to Craig, the entire disclosure of which is hereby incorporated herein by reference.

[0014] According to all of the above-described embodiments, the proppant material may comprise substantially any substrate material that does not undesirably chemically interact with other components used in treating the subterranean formation. It is understood that the proppant material may comprise sand, ceramics, glass, sintered bauxite, resin coated sand, resin beads, metal beads and the like.

[0015] The following examples are illustrative of the methods and compositions discussed above.

EXAMPLE 1

[0016] A total of three separate hydraulic fracturing treatments were performed in a subterranean formation penetrated by a well bore. For each fracturing treatment, sufficient metal tracer was added to a liquid hardenable resin to provide an initial concentration of 1000 ppm of the metal tracer in the resin treated proppant. Cuprous oxide, manganese oxide, and zinc oxide were used as tagging agents in fracturing treatments 1, 2, and 3, respectively. Samples of flowback proppant were collected during the flow back of the well. Each proppant sample was weighted and digested in concentrated nitric acid before being measured against known, calibrated metal concentrations according to the Inductive Coupled Plasma (ICP) method for the ARL Model 3410 ICP which is commercially available from the Thermo ARL business unit of Thermo Electron Corporation. Table 1 shows the concentrations of each metal obtained in each proppant flowback sample. The data indicated that the highest concentration of flowback proppant was produced from the interval of the well that was fractured in the second fracturing treatment.

Table 1

	Frac Treatment 1	Frac Treatment 2	Frac Treatment 3
Sample Number	Cu (ppm)	Mn (ppm)	Zn (ppm)
1	1.9	217.3	11.5
2	2	219.2	11.8
3	2.8	120.5	9.1
4	3.1	204.1	12
5	670.6	382	24.1
6	51.6	214.1	15.3
7	7.3	234.5	13.3
8	2.7	437.7	17.1
9	2.3	183.8	11.9
10	2.7	220.2	12.8
11	2.9	465	19.3
12	2.1	408.1	17.4
13	2.7	577.2	19.3
14	3.1	410.2	18.2
15	2.3	342.9	40.2
16	2.1	299.8	14.9
17	6.5	296.8	12.5

Table 1 (continued)

	Frac Treatment 1	Frac Treatment 2	Frac Treatment 3
Sample Number	Cu (ppm)	Mn (ppm)	Zn (ppm)
18	2.1	494.8	18
19	51	385.8	16.5
20	2.7	443.8	17
21	2.8	564.8	44.6
22	35.5	551.8	16.1
23	2.4	545.8	23.3
24	2	538.8	14.7
25	181	342.8	16.6
26	1.5	119.8	10.3
27	1.4	34.8	11.9
28	1.9	204.8	43.2
29	2	240.8	13.7
30	2.4	175.8	11.3
31	7.5	171.8	10.9
32	2.3	57.8	7.7
33	5.8	192.8	17
34	1.7	188.8	12.1
35	1.9	115.8	9.6
36	2.1	168.9	11.1
37	1.6	245.3	13
38	1.7	173.9	11.6
39	1.9	219.4	12.9
40	1.9	224.6	12.6
41	2	383.3	17.1
42	1.7	284.7	12.5
43	1.9	270.6	13.4
44	2.4	311	12.7
45	1.9	177.1	10.3
46	1.8	304.2	12.9
47	2.4	343.2	13.3
48	2	308.2	12.6
49	5.4	241.6	11.2
50	3.4	209.1	11.4
51	3.3	217.1	11.1
52	1.9	299.7	12.7
53	2.3	228.6	11.4

Table 1 (continued)

	Frac Treatment 1	Frac Treatment 2	Frac Treatment 3
Sample Number	Cu (ppm)	Mn (ppm)	Zn (ppm)
54	1.5	162.8	10.1

EXAMPLE 2

[0017] A total of five separate hydraulic fracturing treatments were performed in a subterranean formation penetrated by a well bore. For each fracturing treatment, sufficient metal tracer was added to the liquid hardenable resin to provide an initial concentration of 1000 ppm of the metal tracer in the resin treated proppant. Manganese oxide, cuprous oxide, zinc oxide, magnesium oxide, and barium oxide were used as tagging agents in fracturing treatments 1 through 5, respectively. Samples of flowback proppant were collected during the flow back of the well. Each proppant sample was weighted and digested in concentrated nitric acid before being measured against known, calibrated metal concentrations according to the Inductive Coupled Plasma (ICP) method for the ARL Model 3410 ICP which is commercially available from the Thermo ARL business unit of Thermo Electron Corporation. Table 2 shows the concentrations of each metal obtained in each proppant flowback sample. The data indicated that the highest concentration of flowback proppant was produced from the intervals of the well that were fractured in fracturing treatments 1 and 5.

Table 2

	Frac Treatment 1	Frac Treatment 2	Frac Treatment 3	Frac Treatment 4	Frac Treatment 5
Sample Number	Mn (ppm)	Cu (ppm)	Zn (ppm)	Mg (ppm)	Ba (ppm)
1	256.9	7.3	18.2	26.8	106.2
2	210.3	14.5	23.1	24	110.6
3	164.5	12.4	20.2	22.5	94.8
4	236.5	9.1	19.9	23.3	100.4
5	97.8	10.5	14.7	19	105.7
6	288.9	2.8	15.8	25.4	110.4
7	202.8	172.8	12.1	21.3	99.7
8	221.3	3	12.8	22.3	115.9
9	167.9	2.9	12.5	21.8	115.7
10	236.1	2.2	12.5	22.8	90.7
11	162.6	1.6	10.8	19.5	85.9
12	111.8	1.6	8.9	18.8	74.9
13	231.8	1.7	11.5	21.7	86.7
14	246.9	2.5	13.1	24.4	98.3
15	348.2	2	13.5	26.8	112.8
16	273.5	2.4	12.4	24.4	101
17	221.5	2	11.4	29.3	83.8
18	268	1.4	11.9	25.8	88.4
19	177.8	1.8	10.4	22.3	77.8
20	247.5	2.4	11.3	28	92.2
21	132.8	1.8	10	22.2	72.4

Table 2 (continued)

	Frac Treatment 1	Frac Treatment 2	Frac Treatment 3	Frac Treatment 4	Frac Treatment 5
Sample Number	Mn (ppm)	Cu (ppm)	Zn (ppm)	Mg (ppm)	Ba (ppm)
22	165.8	2.3	9.4	20.9	75.3
23	306.9	66.4	11.9	28.7	103.8
24	205.7	1.6	9.4	23	87.1
25	241.2	2.6	10.6	23.4	90.4
26	197.6	2.2	10.1	24.1	88
27	242	2.3	10.7	26.2	98.9
28	202.8	3	10.8	24.6	94.6
29	165.7	2	9	20.7	85.5
30	138.3	1.4	8.7	21.3	76.1
31	227.4	1.5	10.3	24	92.8
32	192.1	1.7	9.8	23.5	86.6
33	201.9	1.2	9.6	22.3	86.4
34	138.4	1.7	8.6	19.8	73.9

Claims

1. A traceable particulate composition for treating a subterranean formation having multiple zones penetrated by a well bore, said composition comprising a particulate material; and a tracking material, wherein the tracking material is selected from metals, metal salts of organic acids, phosphorescent pigments, fluorescent pigments, photoluminescent pigments, oil soluble dyes, oil dispersible dyes and oil dispersible pigments.

2. A composition according to claim 1, wherein the tracking material comprises a metal selected from Groups I to VIII of the Periodic Table and the lanthanum series rare earth metals; provided that the metal is not a component of the particulate material; and provided that the metal is compatible with the fluids disposed within the well bore.

3. A composition according to claim 1 or 2, wherein the tracking material comprises a metal selected from gold, silver, copper, aluminum, barium, beryllium, cadmium, cobalt, chromium, iron, lithium, magnesium, manganese, molybdenum, nickel, phosphorus, lead, titanium, vanadium and zinc, and oxide, phosphate, sulfate, carbonate and salt derivatives thereof, preferred oxides being manganese oxide, cuprous oxide, zinc oxide, magnesium oxide, and barium oxide.

4. A composition according to claim 1, wherein the tracking material is selected from metal salts, metal oxides, metal sulfates, metal phosphates and metal salts of organic acids and the metal is selected from chromium, molybdenum, tungsten, manganese, technetium, rhenium, lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium and lutetium.

5. A composition according to claim 4, wherein the tracking material comprises a metal salt of an organic acid and the organic acid is selected from substituted and unsubstituted alkanoic carboxylic acids, alkenoic carboxylic acids, polyunsaturated aliphatic monocarboxylic acids and aromatic carboxylic acids.

6. A composition according to claim 5, wherein the organic acid comprises an alkanoic carboxylic acid having from 5 to 35 carbon atoms, or an alkenoic carboxylic acid having from 5 to 30 carbon atoms.

7. A composition according to claim 5, wherein the organic acid comprises a polyunsaturated aliphatic monocarboxylic acid selected from sorbic acid, linoleic acid, linolenic acid and eleostearic acid, or an aromatic acid selected from

benzoic acid, salicylic acid, cinnamic acid and gallic acid.

8. A composition according to claim 1, wherein the tracking material is selected from phosphorescent pigments, fluorescent pigments and photoluminescent pigments prepared from materials selected from alkaline earth aluminates activated by rare earth ions, zinc sulfide phosphors, aluminate phosphors, zinc silicate phosphors, zinc sulfide cadmium phosphors, strontium sulfide phosphors, calcium tungstate phosphors and calcium sulfide phosphors.

9. A method of treating a subterranean formation having multiple zones penetrated by a well bore which method comprises introducing a traceable particulate composition as defined in any of claims 1 to 8, into each zone using a different particulate composition in each zone to provide a different tracking material in each zone; flowing fluid back from the subterranean formation whereby at least a portion of at least one of the particulate compositions flows back from the subterranean formation; and identifying each zone in which the at least one particulate composition was introduced by detecting the tracking compositions in the fluid that flows back from the subterranean formation.

10. A method according to claim 9, wherein the particulate composition further comprises a material selected from fibrous materials, tackifying agents and deformable beads.

11. A method according to claim 9 or 10, wherein the tracking material is blended with a resin to form a tracking material-resin mixture and the particulate material is coated with the tracking material-resin mixture.

12. A method according to claim 9 or 10, wherein the particulate material is tagged with the tracking material.

13. A method according to claim 9, 10, 11 or 12, wherein the tracking material in the fluid that flows back from the subterranean formation is detected by an inductively-coupled plasma method.

14. A method of propping multiple fractures in a subterranean formation penetrated by a well bore comprising: placing a proppant composition in each fracture in the subterranean formation, wherein each proppant composition comprises particulate material and a tracking composition, and wherein each proppant composition comprises a different tracking composition; flowing fluid back from the subterranean formation whereby at least a portion of at least one of the proppant compositions flows back from the subterranean formation; and identifying each fracture in which the at least one proppant composition was placed by detecting the tracking compositions in the fluid that flows back from the subterranean formation.

15. A method according to claim 14, wherein the proppant composition is a traceable particulate composition as claimed in any of claims 1 to 8.

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 03 25 2392

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	4 August 2003	Boulon, A

CATEGORY OF CITED DOCUMENTS

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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 03 25 2392

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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